(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COST-EFFECTIVENESS METHODOLOGY FOR EVALUATING A TACTICAL COMMUNICATIONS SYSTEM IN THE KOREAN ARMY.

by

Seo, Young Uk

March 1988

Thesis Advisor Kent D. Wall

Unclassified

security classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified	1b Restrictive Markings
2a Security Classification Authority	3 Distribution Availability of Report Approved for public release; distribution is unlimited.
2b Declassification Downgrading Schedule	
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School; 6b Office Symbol (if applicable) 32	7a Name of Monitoring Organization Naval Postgraduate School
6c Address (city, state, and ZIP code) Monterey, CA 93943-5000	7b Address (city, state, and ZIP code) Monterey, CA 93943-5000
8a Name of Funding Sponsoring Organization; 8b Office Symbol (if applicable)	9 Procurement Instrument Identification Number
8c Address (city, state, and ZIP code)	10 Source of Funding Numbers: Program Element No / Project No / Task No / Work Unit Accession No

11 Title (include security classification) COST-EFFECTIVENESS METHODOLOGY FOR EVALUATING A TACTICAL COMMUNICATIONS SYSTEM IN THE KOREAN ARMY

12 Personal Author Seo, Young Uk

13a Type of Report	13b Time Covered	14 Date of Report (year, month, day)	15 Page Count
Master's Thesis	From To	March 1988	77

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms (continue on reverse if necessary and identify by block number)
Field	Group	Subgroup	Cost-Effectiveness, LCC, MOE, NTCS, FOM, Cost Model, C-E ratio

19 Abstract (continue on reverse if necessary and identify by block number)

Cost and Effectiveness models are developed for selecting a new tactical communication system in the Korean Army. Alternatives included an "off-the-shelf" purchase of existing U.S technology and four variants a "self-developed" system . Since exact quantitative military data was not obtainable for security reasons, a subjective approach is taken. Sensitivity analysis is employed to account for errors in effectiveness evaluation and in value assessment. This research recommends the use of the cost-effectiveness methodology in order to provide for selecting a future Korean tactical communications system.

20 Distribution Availability of Abstract ☒ unclassified unlimited ☐ same as report ☐ DTIC users	21 Abstract Security Classification Unclassified	
22a Name of Responsible Individual Kent D. Wall	22b Telephone (include Area code) (408) 646-2158	22c Office Symbol 64Wl

DD FORM 1473,84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete — security classification of this page

Unclassified

Approved for public release; distribution is unlimited.

Cost-Effectiveness Methodology for Evaluating a Tactical Communications System in the Korean Army

by

Seo, Young Uk
Major, Korean Army
B.S., Korean Military Academy, 1978

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1988

Author: ______________________
Seo, Young Uk

Approved by: ______________________
Kent D. Wall, Thesis Advisor

____
Dan C. Boger, Second Reader

____
David R. Whipple, Chairman,
Department of Administrative Sciences

____
James M. Fremgen,
Acting Dean of Information and Policy Sciences

ABSTRACT

Cost and Effectiveness models are developed for selecting a new tactical communication system in the Korean Army. Alternatives included an "off-the-shelf" purchase of existing U.S technology and four variants a "self-developed" system . Since exact quantitative military data was not obtainable for security reasons, a subjective approach is taken. Sensitivity analysis is employed to account for errors in effectiveness evaluation and in value assessment. This research recommends the use of the cost-effectiveness methodology in order to provide for selecting a future Korean tactical communications system.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

Since the cease fire was signed in 1953, the Korean Army has developed its own tactical communication system at division and corps level. The experience of warfare focused attention on the vital importance of communication in determining the success or the failure of combat. In the 1970's almost all communication equipments fielded in the division were changed in response to a requirement to enhance the effectiveness of Army operations. In the FM and AM equipments, AN PRC-9 and 10 were replaced by AN PRC-77 and AN GRC-87, 165 were deployed with all units below the division. The VHF network equipments that is the backbone system of the tactical mobile communication in the corps appeared beside of the old equipments.

In the 1980's, the Korean Army needed to change the method of communications system in order to keep up with the development of the digital and the analog communication systems. The new VHF digital tactical communication equipments have been selected as the hub network of the division and the corps. By now these simply-operated and highly-effective equipments have served the subscribers as the major network in the Army combat areas.

The fast development of the electronic warfare has emphasized the survivability, high security, and decentralization in the Army tactical communication system. Especially, a dynamic communication system is needed to be able to give more effective services to the mobile subscribers within the operation areas. Since these problems could not be solved simply by replacing the new equipments, the Korean Army has stressed heavily the new tactical communication system to meet the requirements needed for the next century's communication system.

Therefore the Korean Army has begun consideration of the MSE (Mobile Subscriber Equipment) system that is to be fielded in the U.S Army during the next 5 years.

B. PROBLEM STATEMENT

The Mobile Subscriber Equipment system, as approved for implementation in the US Army, is an integrated corps-division network of smaller, more survivable communications nodes configured in an area common users communication grid system [Ref. 1: p.34]. The MSE system was selected by USA to satisfy modern battlefield requirements by providing secure mobile communications, rapid replacement, system flexibility,

reliability and survivability by USA. If the needs of the Korean Army are about same to those of USA, an "off-the-shelf" procurement can be taken to save considerable time and money in place of the traditional procurement cycle. Since, however, the desired requirements of the Korean Army are different than those of the USA, this new system should be considered to fit the limited conditions of the Korean Army in light of the cost and the level of capabilities required. Hence the Korean Army has to evaluate these factors and determine whether to procure the MSE as "off-the shelf" in meeting an urgent need for better communication.

Secondly, a " home-made " system can be focused on in order to be suitable to the specific requirements of the ROKA (Republic Of Korean Army). Especially, a self-developmental communication system may be given consideration by the Korean Army to change the conventional system to a new system more smoothly without great troubles of interoperations. This conventional procurement method might reduce some risks that an "off-the-self" system may raise difficulties for test and evaluation. Therefore, the relevant measures of effectiveness of a "home-made" system should be evaluated and compared with the MSE and the conventional communications system.

If both the first alternative and the second candidate are potentially useful, that is, if not only the MSE system might fit to the requirements of the ROKA but also the self-developed system can be advanceed to meet the needs of the ROKA, a decision-maker should choose the best one among them. The methodology of cost-effectiveness will pave the way for selecting the best choice to satisfy the requirements of ROKA.

C. OBJECTIVES

The overall objective of this thesis is to develop a cost-effectiveness(CE) methodology to help a decision maker in selecting a tactical communication system in the Korean Army. The specific sub-objectives are as follows:

- To develop the cost models for the next new tactical communication system of the ROKA
- To develop relevant effectiveness evaluation criteria by adapting existing evaluation models that are used for the military cases (TRI-TAC).
- To integrate the cost and the effectiveness models with cost-effectiveness methodology.
- To demonstrate the methodology by application to the communication system selection of the ROKA.

II. THE BASIC CONCEPT OF COST-EFFECTIVENESS ANALYSIS

A. GENERAL CONCEPT

The interest generated within the last few years in systems engineering has resulted in a growing awareness of a need for measures of effectiveness of systems in relationship to their costs. Cost effectiveness is a measure of effectiveness of systems in relationship to their cost. J. Morley English made mention that cost effectiveness analysis is a very practical management tool to assist and advise decision makers at all levels. It is a type of analytical study that is "designed to assist a decision maker in identifying a preferred choice among possible alternatives " [Ref. 2: p. 1]. In the book of Logistics Engineering and Management, Benjamin S. Blanchard states that "Cost effectiveness relates to the measure of a system in terms of mission fulfillment (system effectiveness) and total life-cycle cost" [Ref. 3: p.19]. On the military side, the TRI-TAC CEPP (Cost Effectiveness Program Plan) defined that the concept of cost effectiveness, the criteria, and the methodology of analysis and estimating used by military research and development management planners and by preliminary design engineers are directly applicable to the management, planning, and control of communication equipment program [Ref. 4: p.4].

In the definitions of cost-effectiveness, all emphasize establishing a basis for making decisions. Regardless of the scale or character of the system to be evaluated, cost-effectiveness in its modern use is concerned with the estimation of costs, the evaluation of the worth or effectiveness, and their combination into useful criteria for decision making.

To integrate the cost with the effectiveness of a system, or vice versa, cost-effectiveness can be quantified in terms of one or more figures of merit (FOM). These two methods for cost-effectiveness comparison can be shown as follows :

$$FOM_i = \frac{LCC(S)}{MOE_i}$$

$$FOM_j = \frac{MOE_i}{LCC(S)}$$

In determining the best one among alternatives available, the smallest FOM_i (the amount of cost per a unit for one MOE), or the largest FOM_j (the amount of capacity

for one MOE per a cost unit ($)) can be selected. That is, the minimal FOM_i or the maximal FOM_j must be considered to help the decision-maker to make a choice.

As mentioned above, cost-effectiveness methods involve the cost and effectiveness of systems. In the next two sections, the evaluations for life-cycle cost analysis and system effectiveness will be described based on each basic concept.

B. COST

1. Life Cycle Cost (LCC) Structure

LCC involves all costs associated with the system life cycle, and LCC analysis constitutes the process of evaluating alternative configurations in terms of LCC figures of merit [Ref. 3: p. 369]. When accomplishing a life-cycle cost analysis, the analyst must develop a cost breakdown structure (i.e., cost tree) showing the numerous categories that are combined to provide the total cost.

The general life cycle cost structure is divided into three major categories: Research & Development (R&D) Cost, Production Cost, and Operating & Support (O&S) Cost. The important elements of these cost categories are shown in Figure 1 on page 5

a. Research and Development Costs : Research and Development costs refer to all government and contractor costs associated with the research, development, test, and evaluation of the system/equipment. Especially these cover all costs during the concept initiation. validation, and full-scale development phase of the program. The Research and development costs are divided into non-recurring and recurring costs. Non-recurring costs refer to R&D costs that are one time costs incurred during the R&D phase.These costs can be incurred again if there is a change in the design, contractor or manufacturing process [Ref. 4: p. 10].

b. Production Costs (Investment Costs) : Investment costs refer to those program costs required beyond the development phase to introduce into operational use a new capability; to procure initial, additional, or replacement equipment for operational forces; or to provide for major modification of an existing capability. Investment costs are further divided into nonrecurring and recurring costs.

c. Operating & Support Costs : This category includes the costs of personnel, material, facilities, training, and other direct and indirect costs required to operate, maintain, and support the equipment/system during the operational phase. It includes the costs of all

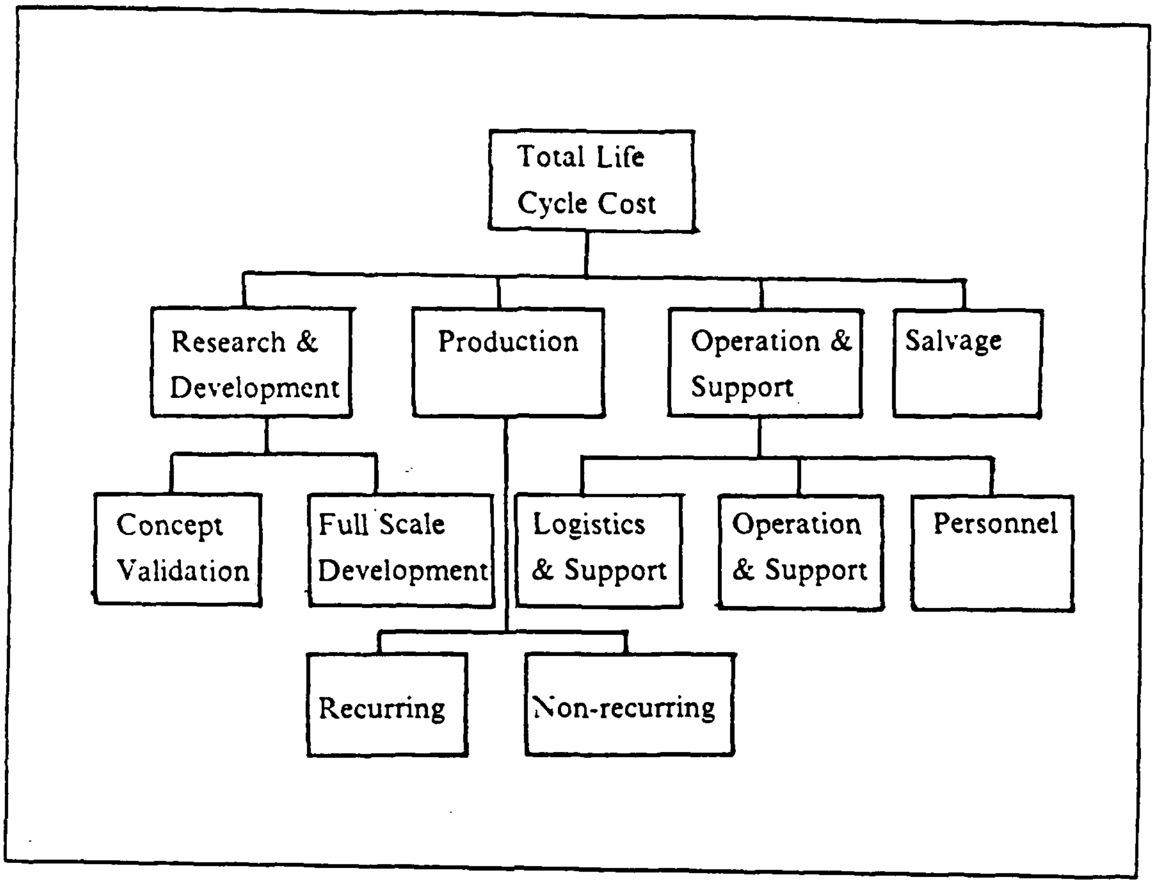

Figure 1. LCC Structure

parts consumed in maintenance of the equipment as well as the equipments and information. [Ref. 4: p. 14].

There is no set method for breaking down cost as long as the method used can be tailored to the specific application. However, the cost breakdown structure should exhibit the basic characteristics, that is, not only all system cost elements must be considered but also cost categories are generally identified with a significant level of activity or some major item of hardware.

2. Cost Model

a. Concept

It may be essential to develop a cost model to facilitate the LCC evaluation process. Cost models, in general, provide essential frameworks of elements, factors, and equations useful for engineers, operations research analysts, and cost analysts to analyze and estimate the resource requirements of proposed future systems, subsystems, and

equipment in terms of dollars. There are many kinds of cost models and many levels of cost aggregation covered. A life cycle cost model deals with estimating total costs associated with the life cycle of systems, equipment, etc.

Two factors influence in a significant way, the scope of a life cycle cost model. These factors are (1) the intended use of the model and (2) the availability of data, both for preparation of the CER's and as inputs to the CER when estimating costs [Ref. 4: p.20].

b. Cost Estimating Relationship (CER)

Estimates of the cost elements can be prepared by several techniques. One of the most common technique is a cost estimating relationship (CER). A CER is an analytical device that relates the value (in dollars or physical units) of various cost categories to the cost-generating or explanatory variables associated with the categories [Ref. 5: p. 123]. There are several major types of cost estimating techniques; parametric, industrial engineering, analogy, and expert opinion.

(1) Parametric Cost Estimating Relationship : A parametric or statistical CER can be derived for new system/equipments if there are historical data from prior system/equipments that are functionally similar.

(2) Industrial Engineering Cost Estimating Relationship : In the past, the principle technique used to support cost estimates associated with electronic systems has been the industrial engineering approach which relies on detailed simulation of all the operations required to develop and produce a unique and specifically defined piece of equipment. This procedure makes use of vendor quotes, man- loading requirements by work center and station, standards built up from time and motion studies, etc., and is sometimes referred to as "grass roots" or "bottom up" estimating. In many cases, the estima- ting is done by a contractor.

(3) Analogy Cost Estimating Relationships : The analogy cost estimating relationships derive costs of new programs from data on past costs of similar programs. This technique frequently involves estimation of the incremental or marginal cost associated with program or equipment changes.

(4) Subjective Cost Estimating Relationships : The subjective or judgemental cost estimating relationships are derived from "engineering judgement" of experts.

c. Types of Cost Models

Cost models may be classified in any several ways. One possible basis of categorizing them is in terms of the extent to which the model manipulates the inputs. Cost models can be categorized according to the function they serve. Some models are designed to assist long-range planners. Others are for use in programming, where this term implies a more detailed level of planning and application in the near future. Still others are designed for use in preparing next fiscal year's conventional budget. Cost models can also be classified in terms of the subject matter they are intended to represent. Some models deal with relatively minor parts of the total subject being considered by a decisionmaker, while others attempt to represent almost the entire structure of the problem.

On the other hand, a cost model may be viewed as an integrating device designed to facilitate the analytical process by bring together the various factors on the input side and relating them to some type of output-oriented military capability in the future.

Cost models may be categorized and discussed in many different ways. Among them, the following can be classified based on the size of the domain being modeled :

(1) Resource requirement submodels
(2) Individual system cost models
(3) Mission area force-mix cost models
(4) Total force cost models

All of these models are important, and military cost analysis depends on all of them. Though the individual system cost models have been used widely, however, the importance of mission area force-mix cost models is growing at the present time. Systems analysts have come more and more to see mission area force-mix comparisons as feasible and meaningful analytical work [Ref. 5: p 200].

3. Discounting, Inflation, and the Learning Curve

When establishing the life cycle cost for use in any cost analysis, discounting, inflation, and the learning curve should be incorporated.

Discounting : The rationale behind discounting future cash flows is the realization that the deferral of expenditures allows the present use of money in alternative investments to yield some beneficial returns. At the present time the standard discount rate specified by DOD is ten percent per year compounded annually. Continuous discounting is to be used in the economic analysis of tactical communications. The continuous discount factor, for time interval t, and discount rate R, is calculated as follows :

$$r = \int_{t-1}^{t} e^{-Rt} dt$$

The present value of any future cost can be obtained by multiplying that cost by the applicable discount factor.

Inflation & Deflation : The preparation of cost estimates for systems and programs involving the acquisition of major communications equipment should involve the consideration of economic escalation associated with the costs used in the estimate. All cost estimates should reflect the best estimate of the amounts ultimately to be paid specifically incorporating anticipated changes in future price levels.

The Learning Curve : The learning curve is based on historical evidence that as the total quantity of units produced increases, the man hours or cost to produce that quantity will be reduced by some percentage. [Ref. 5: p 46-47].

The general form of the equation is like this:

$$Y = AX^{b}$$

where

Y = cost for unit

A = the cost to produce the first unit

X = the cumulative output

b = the slope of the learning curve

4. Methodology for LCC Analysis

Following steps present a general methodology that should be followed in estimating life cycle costs for use in any cost analysis of joint tactical communication programs. Analyst should, however, tailor their LCC methodology to be applicable to the specific analysis to be conducted for a particular communications hardware and software [Ref. 4: p 26].

The steps in the methodology are :

a. State study objectives

b. Define assumption

c. Select cost elements

d. Select cost estimating relationships (CER)

e. Collect data

f. Estimate element costs

g. Perform sensitivity analysis

h. Present results

The first step of the methodology is to identify, formulate, or state the objectives of the analysis or study which originally generated the need for the cost estimating exercise. The statement of the objectives is an important part of the analysis effort and might require updating and redefining following evaluation and feedback. The adoption of valid assumptions that underlie the estimating process in life cycle costing is critical if the exercise is to yield useful results. Assumptions are often necessary to make the abstract cost model more representative of the proposed real world, because all specific detailed inputs are not always available, particularly for "far-out" systems.

The analyst should select cost elements as required for the specific analysis using the following guidelines:

- All cost elements will be chosen from the cost breakdown structure.
- The analyst should select cost elements in as much detail as practicable for the cost model. Cost elements for sunk cost categories need not be considered.
- There are times when costs can not be broken out into separate cost elements. The analyst can estimate costs for the higher level cost category in this case. This estimate might be refined in later analyses when further information becomes available.

The procedure for estimating each cost element must be specified. The analyst can select a parametric, an engineering, an analogy, or subjective CER for the cost

model. One of the greatest problems in estimating life cycle costs is the collection and validation of data. The analyst can avoid generating unnecessary work by determining whether adequate information is already available. After the necessary input data has been collected and validated, estimates of element cost can be obtained through the use of relevant CER's. The analyst should also estimate the degree of cost uncertainty. If a quantitative measure cannot be obtained, the analyst should make a qualitative judgement on the significance of the cost estimates. The sensitivity analysis aids the analyst in determining uncertainty in life cycle cost estimates. All cost estimates should be examined for both validity of the inputs and the contribution of the element cost to the total life cycle cost. Monte Carlo methods can also be used in the evaluation of cost uncertainty. A Monte Carlo method is any procedure that involves statistical sampling techniques from a distribution of possible outcomes for obtaining a probabilistic approximation to the solution of a problem. It is important that the steps followed in the analysis and the analysis results be adequately documented. The documentation of the life cycle costing effort can now be combined with the results of system effectiveness analysis and used in the cost effectiveness analysis of tactical communication system equipment. [Ref. 5: p 28-34].

C. SYSTEM EFFECTIVENESS

1. General Concept

System effectiveness is often defined in general terms as a measure of extent to which a system can be expected to achieve a set of specific mission requirements. This measure of achievement is considered to be a function of at least three important operational aspects. These are :

a. Availability : is a measure of the system condition at a start of a mission and is a function of the relationships among hardware, personnel, and procedures including reliability and maintainability.

b. Dependability : is a measure of the system condition at one or more points during the mission; given the system condition(s) at the start of the mission and may be stated as the probability that the system (1) will enter and/or occupy any one of its sig- nificant states during a specified mission and, (2) will perform the function associated with those states.

c. Capability : is a measure of the ability of a system to achieve the mission objectives: given the system condition(s) during the mission and specifically accounts for the performance spectrum of a system.

More likely, the concept of a Figure of Merit (FOMs) would be used to serve as an index of the estimated quality of the system as it might operate under some assumed scenario [Ref. 6: p 4-5].

2. Measure of Effectiveness Structure

A conceptual model is one which describes overall logic, principle elements, basic parameters, important assumptions, and "defining equations", which serve as guidance for follow-on preparation of more detailed models for specific design optimization problems. Before measuring the effectiveness of a system, the analyst must determine the elements which are appropriate for evaluating system effectiveness. Table 1 shows the 16 elements of system effectiveness which can be segregated into four groups.

Table 1. MEASURE OF EFFECTIVENESS STRUCTURE

Communication Measures	
	Grade of Service
	Information Quality
	Speed of Service
	Call Placement Time
	Service Features
	Lost Message Rate
	Spectrum Utilization
Stability Measures	
	Index of Survivability (Overt)
	Index of Survivability (Jamming)
	Index of Availability
	Interrupt Rate
Reorganization Measures	
	Transportability
	Mobility
	Ease of Reconfiguration
	Ease of Transition
	Interoperability
Security	

These groups are significant to various types of management planners. Each of the three categories relates system effectiveness to different kinds of interest. The Communication Group identifies those aspects of the communication systems and equipments that are of primary interest to the service communicators and to the communication engineer. The Stability Group is of primary interest to the operators of the system, as well as the reliability and maintainability engineers and logistics support designers. The Reorganization group is of interest to commanders who are forced to move parts of a system during conflict, and to the mechanical designers and engineers who must design equipment for ease of movement.

The Security Measure Group treats those COMSEC MOEs which consider how well a system can protect information that is being transported through the system from unauthorized personnel or otherwise be compromised or spoofed. [Ref. 7: p. 12].

3. System Effectiveness Methodology

In the case of effectiveness analysis, the multi-attributes are the various MOEs that have been chosen to represent the effectiveness of the alternatives. The methods presented fall into the following categories :

a. Full Dimensionality Methods : consists of starting with n-attributes (dimensions) and reducing the dimensionality to some lower value. The attributes must be considered separately. and independently. They can be described quantitatively, qualitatively, or by a combination of both.

b. Single Dimensionality Methods : reduces n-dimensions to one-dimen- sion by removing all but one dimension. Transformations that map into a single dimension and perform this reduction are Maximin, Maximax, Lexicographic, Additive Weighting, Effectiveness Index, and Utility Theory.

c. Intermediate Dimensionality : Between the two major dimensionality categories lie procedures that deal in more than one but less than the full n-dimensions. Two methods that address the multiple attribute problem under this constraint are trade-offs and nonmetric scaling.

d. TRI-TAC FOM : The TRI-TAC FOM was developed to specifically combine multi-MOE assessments for subsystem planning evaluations. The method is a combina-

tion of additive weighting, effectiveness index and utility theory, and can be used to produce a single numerical effectiveness result from quantitative assessment, qualitative assessments, or both types of assessments. The method consists of the following basic steps :

- Establish MOE weight
- Assign Utilities to MOE assessments
- Calculate the FOM

In this thesis, FOM will be used to evaluate multi-MOE assessments. The first step in obtaining a FOM is to establish relative weights for the MOEs in the evaluation, and to assign utilities to the MOE assessments.

The function is subjectively assigned in accordance with Table 2.

Table 2. UTILITY CRITERIA

Utility	Criteria
0 - 2	Barely meets minimum essential requirements
2 - 4	Less effective than the baseline
5	Baseline
6	Slightly better than the baseline
7	More effective than the baseline
8	Much more effective than the baseline
9 - 10	Superior effective to the extent that the MOE should be a principle consideration in the selection of a preferred alternative.

To assign utilities to the alternatives using Table 2 the following procedure can be employed :

- Rank alternatives in accordance with their relative performance under the MOE (can be quantitative or qualitative).
- Assign the median alternative a utility of 5; this becomes the baseline alternative.
- Assign utility to the remaining alternatives in accordance with the table.

The last step in obtaining a MOE is to combine the weighting and utility information using the following formula to calculate the FOM of each alternative.

$$FOM_i = \frac{\Sigma W_j U_{ji}}{\Sigma W_j}$$

where

FOM_i =the figure of merit for the ith alternative

W_j =the weight of the j sup th MOE

U_{ji} =the utility assigned to the ith alternative with repect to the j^{th} MOE

It should be noted that this approach magnifies the differences between alternatives. An alternative method would be to consider the weights and utility values of all MOEs. [Ref. 6: p. 29-37].

D. STANDARD APPROACH TO COST-EFFECTIVENESS EVALUATION

The basic concept inherent in cost-effectiveness have been applied to a broad range of problems. In evaluating the cost-effectiveness of a system the following prerequisites should be recognized:

- Common goals, purpose, and mission of the system must be identifiable and at least theoretically attainable.
- Alternative means of meeting the goals must exist.
- Constraints for bounding the problem must be discernible.

The following steps define the execution of the cost-effectiveness evaluations in this thesis:

- Define the desired goals, objectives, missions, or purposes that the systems are to meet or fulfill.
- Develop the cost model for a system
- Establish system evaluation criteria (measures) that relate system capabilities to the mission requirements.
- Develop alternative concepts for accomplishing the missions.
- Calculate the LCC for alternatives available
- Determine FOMs of relevant MOEs using the criteria developed by the TRI-TAC agency
- Generate alternatives-versus-LCC, FOM, and C/E arrays.

- Analyze alternatives for selection of a better alternative
- Perform sensitivity analysis to reduce the risk of uncertainty

[Ref. 8: p.113-140].

III. COST MODEL

A. INTRODUCTION

The NTCS system may be a multichannel communication network for use at the division and corps level in the ROK Army. The network is compsed of primary nodes that form a backbone system and extention nodes and Radio Access Units (RAU) that provide users access to the system. The primary nodes are interconnected by multichannel radio links to form a grid system. Extention nodes and RAUs access the communication network by means of multichannel radio links connecting them to primary nodes.

The NTCS system is designed to provide communication support as an integrated network at the corps and division level. For a corps force composed of 3-5 divisions, Each of the primary nodes in the backbone is generally connected to 3-5 other primary nodes to form the backbone grid. Extention nodes and RAUs are usually provided multichannel radio links to two of the primary nodes in the backbone system, with one link active while the other is in a standby condition to provide backup as needed.

Extention nodes provide access to the backbone network for static subscribers. Mobile subscribers are provided access to the network by means of the Radio Access Units. Each of the individual pieces of terminal equipment used by subscribers are assigned a directory number that remains constant regardless of where the subscriber may move within the system. This feature allows subscribers to be accessed regardless of their location within the service area of the system.

Among the four types of cost models, the individual system cost models, will be adapted to this thesis. To develop the cost model for the new tactical communication system (NTCS), first, set up the life cycle cost structure for this system, then identify the cost elements which can be considered, and last develop the cost models.

This system must have high mobility features, interoperability, antijamming capability, and other capabilities that are required of battle field communications. Proposals for a future system must be evaluated in terms of reducing costs compared with the effectiveness.

The assumption will be given to avoid complexity to be manageable for this new communication system. General assumptions for the development of the model are as follows :

- R&D cost will not be calculated using the model due to the lack of data. Instead this cost will be estimated as a proportion of the procurement cost based on the U.S Army budget for electronics and communications from 1982 to 1986.
- Salvage cost incurred at the end of the life-cycle will be negligible, that is, it is assumed to be zero.
- The utilization of current equipments available will be maximized.
- The time horizon will be considered from 1991 to 2010 (20 years).
- This thesis will be focused on the investment cost and the operating & support cost.

Total system cost will be calculated as follows :

$$TSC = \Sigma\left(\frac{1}{1+r}\right)^t (R(t) + I(t) + A(t))$$

where

```
R(t)= Research & Devlopment costs during the time t
I(t)= Investment costs during the time t
A(t)= Operating costs during the time t
r = discount rate
```

B. COST STRUCTURE

To accomplish a life-cycle cost (LCC) analysis, a NTCS cost breakdown structure is needed. Figure 2 on page 18 presents the structure used in this thesis.

C. COST ELEMENTS

The total system LCC structure of NTCS is subdivided to lower level cost elements shown in Table 3 on page 19.

1. Research & Development Cost

This cost includes program management cost, advanced research and development cost, engineering design cost, equipment development and test cost, and engineering data cost.

a. Program Management Cost

It refers the costs of management oriented activity applicable (across-the-board) to conceptual/feasibility studies, research, engineering design (including logistic

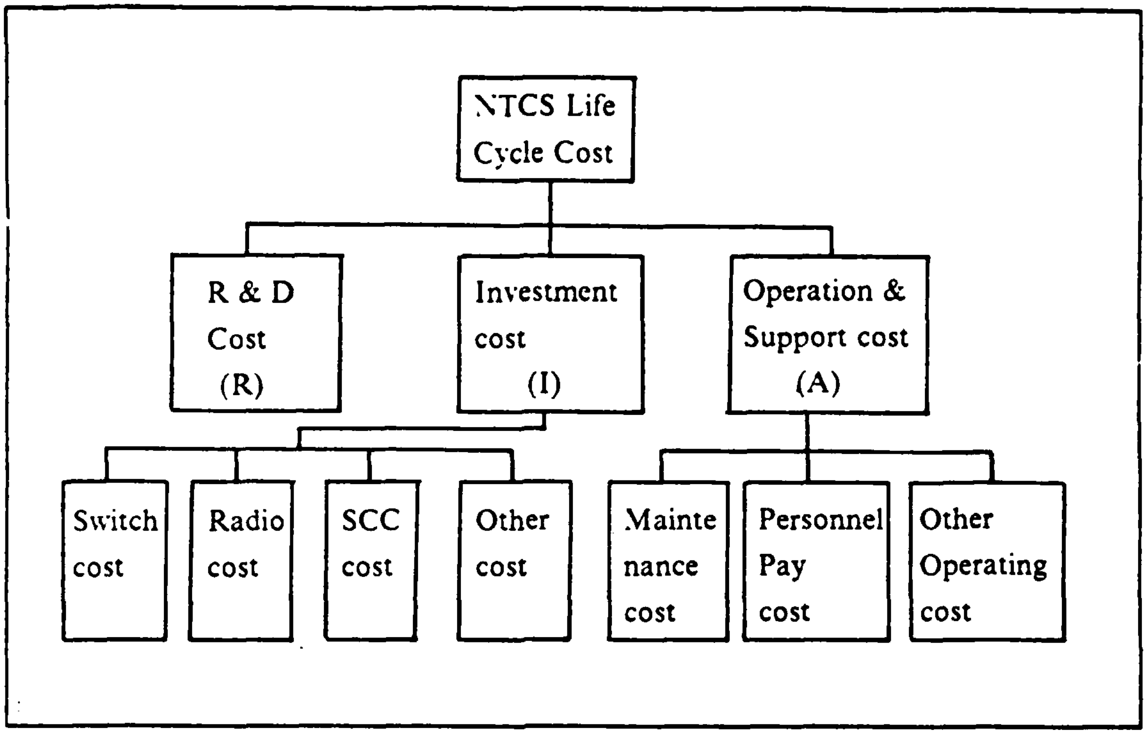

Figure 2. NTCS Cost Breakdown Structure

support in the design process), equipment development and test, and related data/documentation. Such costs cover the program manager and his administrative staff; marketing; contracts; procurement; configuration management; logistics management; data management; etc.

b. *Advanced Research and Development Cost*

Advanced research includes conceptual/feasibility studies conducted to determine and/or justify a need for a specific requirement. This includes effort oriented to defining mission scenarios, system operational requirements, preliminary maintenance concept, etc., accomplished early in a program.

c. *Engineering Design Cost*

This cost includes all initial design effort associated with system/equipment definition and development. Specific areas include system engineering; design engineering; reliability and maintainability engineering; human factors; functional analysis and

allocation; logistic support analysis; components; producibility; standardization; safety; etc.

Table 3. NTCS COST ELEMENT

1.0 R & D Cost (R)
2.0 Investment Cost (I)
2.1 Switch Investment Cost
2.1.1 Node Center Switch & Large Extension Switch
2.1.2 Small Extension Switch
2.2 Radios Investment cost
2.2.1 Mobile Subscriber Radio Terminal
2.2.2 Line-of-Sight Multichannel Equipment
2.2.3 Down-the-Hill SHF radio
2.2.4 Radio Access Unit
2.3 System Control Center Cost
2.3.1 Command Shelter
2.3.2 Technical Shelter
2.3.3 Planning Shelter
2.4 Other Equipments Cost
2.4.1 Digital Non-secure Voice Terminal
2.4.2 Teletype Terminal
2.4.3 Data Terminal
2.5 Initial Inventories of Spares and Spare Parts for Equipments Cost
2.6 Initial training Cost
2.7 Miscellaneous Investment Cost
3.0 Operating & Support Cost (A)
3.1 Maintenance Cost
3.2 Personnel Pay & Allowance
3.3 Miscellaneous Annual Operation Cost

d. *Equipment and Development Cost*

The fabrication, assembly, test and evaluation engineering prototype models is included herein. Specifically, this constitutes fabrication and assembly; instrumentation; quality control and inspection; material procurement and handling; logistic support; data collection; and evaluation of prototypes.

e. *Engineering Data Cost*

This category includes the preparation, printing, publication, and distribution of all data documentation associated with these costs explained above. This covers program plans; R and D reports; analyses; preliminary operational and maintenance procedures; and all effort related to a specific documentation requirement [Ref. 4: p. 373-374].

2. Investment Cost

Investment cost consists of seven elements, which are switch investment costs, radio investment costs, SCC cost, other equipments cost, initial inventories of spares and spare parts for equipments costs, initial training costs, and miscellaneous investment costs.

a. *Switch Investment Cost*

There are two types of switches. One is the large accessable switch which will be installed in Node Center (NC) and Large Extension Node (LEN), the other is the small accessable switch for Small Extension Node (SEN). The cost of these circuit switches can be divided into hardware cost and software cost.

In the hardware point of view, Node Center Switch (NCS) and Large Extension Switch (LES) will be all digital switches that performs flood search routing for locating subscribers of the network. The NCS and LES will accommodate Digital Transmission Groups (DTGs), Trunk Encryption Devices (TEDs), Orderwire Control Unit, and High Mobile Multipurpose Wheeled Vehicle (HMMWV). Above all, switch investment cost will be changed, depending on the number of DTGs of a switch. Furthermore, TEDs cost is determined to how many DTGs will be encrypted using TEDs. TEDs cost may be 20 to 50 percent of the total equipment cost. The weight of a switch may be a cost factor to enhance the mobility, however, it will not heavily affect the variance of cost, because of no great difference between the weight of digital electronic equipments.

On the other hand, software cost is increasing year by year. According to how many features of service a switch will have, software cost will be determined. It may be more than hardware cost of a switch. Therefore, Software cost may be a key parameter in determining the cost of a switch in the future.

b. Radio Investment Costs

Radio groups can be divided into four equipments, which are Line-of-Sight (LOS) Multichannel equipment, SHF Down-the-Hill radio, Radio Access Units(RAU), and Mobile Subscriber Radio Terminal (MSRT). Among them LOS multichannel and SHF radio can be replaced by current equipments operated in the Korean Army. Only the cost factors of radio used in RAU and MSRT will be considered in this thesis.

Radio investment cost may be the function of output power of transmitter as well as dimension of it. Of course, the number of channel and the types of modulation scheme, and coding scheme can be the cost factors in selecting the requirements for the design of radio. However, above all, the capability of output power will be a major parameter in determining this radio investment cost for RAU and MSRT.

c. System Control Center Cost

The NTCS control center will be composed of the basic hardware and some software. Three assemblages that make up the hardware elements of the SCC will be reconfigured, downsized, and mounted in S-250 extended shelters and transported by the HMMWV. These three shelters are the command shelter, the technical shelter, and the planning shelter. The cost of these equipments will be estimated as the same cost of those by MSE system.

d. Other Investment Cost

This cost consists of the Data Terminal (DT) cost, Teletype Terminal (TT) cost, and Digital Non-secure Voice Terminal (DNVT) cost. These costs will be also estimated as the cost of same equipments used in MSE system.

e. Initial Inventories of Spares and Spare Parts for Equipments Cost

This cost includes spares material stocked at the various inventory points to support the maintenance needs of prime equipment, test and support equipment, and training equipment.

f. Initial Training Cost

Training costs will consider the original costs (equipment acquisition), initial training cost and the recurring training costs associated with the item to be procured. However, only initial training cost will be considered in this category.

Initial training costs consist of all initial costs of training cadre personnel. These costs will typically include such that items as trainee salary, per diem, travel expense, etc. Again, these may be divided to identify training for various levels of maintenance and operations. In computing the cost of making trainee and/or instructors available, the Government shall apply the standard rates specified in the Composite Standard Military Rates for Costing of Military Personnel Services and shall assume an eight-hour day for such personnel. Per diem shall be based on the current rate for the type of personnel in question (military/civilian). Travel expenses to the Government shall be predicted on the basis of coach class air fare [Ref. 7: p. 4-3].

In actual practice, manpower submodels are often quite complex. They must distinguish between officers, enlisted men, and civilians; and more often than not, such models will provide for further classification within these three categories. They also often provide for estimating requirements for operations and maintenance personnel as functions of the major equipment characteristics, system operation concepts, and the like. In many cases the personnel calculation is very important because total system cost is often very much a function of the numbers and types of manpower required to man the system [Ref. 5: p. 175].

g. *Miscellaneous Investment Cost*

This cost is made up of the inventory management cost, system test & evaluation, system/project management cost, and recurring investment cost. In this thesis these costs will be aggregated into one cost named Miscellaneous Investment Cost.

3. Operating & Support Cost

a. *Equipment Maintenance Cost*

This cost includes all action taken to retain an end item in a serviceable condition or to restore it to serviceability. It includes inspection, testing, servicing, classification as to serviceability, repairs, overhaul, rebuilding, test and reclamation.

b. *Personnel Pay & Allowance*

This cost element is the manpower cost, direct and indirect, that is incurred in the supply function. Included is not only the cost of the personnel pay and allowances, but also the miscellaneous expenses, support costs, and incentive and special pay.

c. Miscellaneous Operating Cost

These elements include the operating cost related to equipment shelters, the cost of transportation of special materials, and transportation cost of the prime mission equipment for the purpose of operation [Ref. 2: p. 9-11].

D. COST MODELS

NTCS (New Tactical Communication System) cost models will be developed based on the method of parametric cost estimation relationship. From the historical data the cost models will be derived. However, parameters of the each equipment considered will be selected subjectively by the author because of the limitation of collecting documents related to this. Furthermore, some equations derived from a missile system will be used in this thesis.

Total NTCS cost is defined as Research and Development cost + Investment cost + Y years Operating cost. These are listed in Table 4 on page 24.

1. Research and Development Cost (R)

This cost consists of five cost elements as followings :

$$R = R_1 + R_2 + R_3 + R_4 + R_5$$

where

R_1 =program management cost

R_2 =advanced R and D cost

R_3 =equipment design cost

R_4 =equipment development and test cost

R_5 =engineering data cost

From the data of US Army Budgets for Electronics(1982 - 1986) in the "Jane's Military Communications", R and D costs for NTCS may be estimated as the following equation ;

$$R = 0.588 \times Investmentcost = 0.588 \times I$$

Table 4. COST CATEGORIES FOR NTCS

R = Research and Development Cost
I = Investment Cost
I_1 =Switch Investment Costs I_2 =Radio Investment Costs I_3 =SCC Investment Costs I_4 =Other Investment Costs I_5 =Initial Inventories of spares and spare parts for Equipments Cost
I_6 =Initial Training Costs I_7 =Miscellaneous Investment Costs
A = Annual Operating Cost
A_1 =Equipment Maintenance Cost A_2 =Personnel Pay and Allowance Cost A_3 =Miscellaneous Annual Operating Cost
TSC = Total System Cost = R + I + AY (Y = number years of system operation)

2. Investment Cost (I)

a. Switch Investment Cost

Switch investment cost includes the Node Center Switch (NCS) cost, the Large Extension Switch (LES) cost, and the Small Extension Switch (SES) cost. NCS and LES will be the same type of switch. On the other hand, SES will be planned to use the current modified switch. Therefore the switch used in the NC and LEN will be focused on in considering switch investment cost.

Switch cost can be separated into hardware cost and software cost which is the cost for operating the switching network system. Software costs of the switching network system may be also treated in the category of software investment cost of this system. However, this cost will be included in the software cost for switch here.

That is :

$$I_1 = I_{11} + I_{12}$$

where

I_{11} =hardware cost

I_{12} =software cost

(1) Hardware Cost of Switches Network System. The hardware cost of switch can be divided into three element costs ; Digital Transmission Groups (DTGs), Trunk Encryption Devices(TEDs), and High Mobility Multipurpose Wheeled Vehicle (HMMWV).

Depending on how many DTGs and TEDs will be accommodated, hardware cost is determined.

$$I_{11} = E + A_1X_1 + A_2X_2$$

where

I_{11} =hardware cost

X_1 =number of DTGs

X_2 =number of TEDs

A_1, A_2 =slope coefficients

E = intercept coefficient

In selecting the capacity for accessing subscribers, the following linear equation is derived, using the analogy method, from the estimated costs equivalent to the equipments used in the MSE system.

$$I_{11} = 0.585 + 0.109X_1 + 0.019X_2$$

(2) Software Cost of Switches Network System. The software cost for digital voice and data traffic is the important determinant to switch in order to improve features of service for subscribers. It depends on to the content what switch can serve the features of service. Especially, program size for the switch is the prime parameter of software estimating cost. There are several types of models developed for estimating the software cost, such as ITT, COCOMO, and Putnam models. However, since the evaluation of methods above is beyond the scope of this thesis, no reference will be made further about that.

Software cost of switching network system is a function of program size to be designed. That is, program size may be a key parameter to determine the software cost estimation.

$$I_{12} = f\ (\text{program size})$$

From the data of Table 13 in Appendix B, the following simple linear equation model may be developed by the regression method :

$$I_{12} = -1.50 + 0.066X_p$$

where

X_{12} =software cost

X_p =program size

b. ***Radio Investment Cost***

Radio investment cost is made up of LOS multichannel equipment cost, Down-The-Hill SHF radio cost, RAU cost, and Mobile Subscriber radio terminal cost.

$$I_2 = I_{21} + I_{22} + I_{23} + I_{24}$$

where

I_2 =Radio investment cost

I_{21} =LOS multichannel cost

I_{22} =DTH SHF radio cost

I_{23} =RAU radio cost

I_{24} =MSRT radio terminal

As referred in the cost element section, I_{21} will be calculated as the cost of current equipment, operated by ROKA and I_{22} will be estimated as the cost of SHF radio cost in MSE system. Therefore, only I_{23} and I_{24} will be considered in this section.

(1) RAU radio costs & MSRT radio costs. RAU will contain Radio Units, Group Logic Unit (GLU), Loop Group Multiplexer, TED, and antenna. Prima-

rily, I_{23} depends on how many radio units will be used to be able to process calls from mobile subscribers simultaneously. MSRT will use the same radio unit of RAU as well.

Among capabilities of a radio level of output power may be the major parameter in determining this cost.

That is :

$$I_{23}, I_{24} = f(\text{ output power })$$

Depending on the output power of several types of transmitters, radio cost will vary as provided in Appendix B. From Table 14 in Appendix B, the following equation may be derived :

$$I_{23} = 0.0053 + 0.002X_1$$
$$I_{24} = N(0.0053 + 0.002X_2)$$

where

X_1 =output power (W)

N = number of MSRT radio

c. *System Control Center cost*

System control center cost is made up of the cost elements: (1) The SCC command shelter cost; (2) The SCC technical shelter cost; (3) The SCC planning shelter cost.

$$I_3 = I_{31} + I_{32} + I_{33}$$

where

I_3 =Total SCC cost

I_{31} =Equipment costs in command shelter

I_{32} =Equipment cost in technical shelter

I_{33} =Equipment cost in planning shelter

This cost also will be evaluated as the same costs of equipments used in the MSE system.

d. Other Equipments Cost

Other equipments cost includes the Data Terminal cost, Teletype Terminal cost, and Digital Non-secure Voice Terminal (DNVT) cost.

$$I_4 = I_{41} + I_{42} + I_{43}$$

where

I_4 =Other equipment investment cost

I_{41} =DT cost

I_{42} =TT cost

I_{43} =DNVT cost

This cost will be estimated as the cost equivalent to the equipments used in the MSE system.

e. Initial Inventories cost of Spare and Spare parts

I_5 may be approximately by taking about 15 % of the investment cost of the total equipment cost.

$$I_5 = 0.15(I_1 + I_2 + I_3 + I_4)$$

[Ref. 5: p. 174].

f. Initial Training Cost

Though DoD has developed the initial training cost model, this will not be used in this thesis, because of complexity of models. Instead suppose that initial training cost for the total system may be estimated using the initial training costs equivalent to the costs for a engineering battalion in US Army.

$$I_6 = 0.023 \times P$$

[Ref. 9: p. d-18].

where

P = total number of personnel per division

p_{om} =number of operations and maintenance personnel per division

p_{as} =number of administrative and support personnel per division

$p = P_{om} + P_{as}$

Operations and maintenance personnel may be estimated as a function of the number of Node Center per division, and incremental administrative and support personnel can be estimated as function of the number of operation and maintenance personnel. The results are as follows :

$$I_6 = 0.023 \times p = 0.023 \times (P_{om} + P_{as})$$

g. *Miscellaneous Investment Cost*

It will be assumed that I_7 can be estimated as a simple linear function of the number division to make the calculation simple :

$$I_7 = 0.25 N_u$$

where

N_u =Number of Node Center in a division

[Ref. 5: p. 176].

3. Annual Operating Cost (A)

a. *Equipment Maintenance Cost*

Suppose that analysis of equipment maintenance activities suggest that annual all equipments maintenance cost may be estimated at about 20 percent of the investment cost of th ıll inventories. On the basis of this, the equipment maintenance cost equation may be corrective as

$$A_1 = 0.2(I_1 + I_2 + I_3 + I_4)$$

b. *Personnel Pay and Allowance Cost*

Assume that A_2 may be approximated by taking a weighted average pay and allowances cost factors and applying to the total number of personnel in NTCS. Annual personnel pay and allowance costs of a battalion are divided by the number of operating and supporting personnel in a signal battalion :

$$A_2 = 0.021P = 0.021(P_{om} + P_{as})$$

[Ref. 10: p. 99].

c. *Miscellaneous Annual Operating cost*

It is assumed that miscellaneous operating cost can be estimated as a simple linear function of the total number of person in the system :

$$A_3 = 0.001P$$

[Ref. 10: p. 99].

E. SUMMARY

Total System Cost is influenced by all the above and the number of years of system operation :

$$TSC = \sum\left(\frac{1}{(1+r)}\right)^t(R(t) + I(t) + A(t))$$

where

R(t)= Research & Devlopment costs during the time t

I(t)= Investment costs during the time t

A(t)= Operating costs during the time t

r = discount rate

Table 5 on page 31 shows the summary of developed cost models.

Table 5. NTCS COST MODEL

$$TSC = \sum\left(\frac{1}{1+r}\right)^t (R(t) + I(t) + A(t))$$

$$R(t) = 0.588 \times I(t)$$

$$I(t) = (I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7)(t)$$

$$I_1(t) = I_{11}(t) + I_{12}(t)$$

$$I_{11} = N_{11}(0.585 + 0.109X_1 + 0.019X_2) + 0.01N_{12}$$

$$I_{12} = -1.50 + 0.066X_p$$

$$I_2(t) = I_{21} + I_{22} + I_{23} + I_{24} = 0.057N_{21} + 0.005N_{22} + (0.0053 + 0.002X_3)N_{23} + (0.0053 + 0.002X_3)N_{24}$$

$$I_3(t) = I_{31}(t) + I_{32}(t) + I_{33}(t)$$

$$I_4(t) = I_{41}(t) + I_{42}(t) + I_{43}(t)$$

$$I_5(t) = 0.15(I_1(t) + I_2(t) + I_3(t) + I_4(t))$$

$$I_6(t) = 0.023 \times P(t)$$

$$I_7(t) = 2.5N_u(t)$$

$$A(t) = A_1(t) + A_2(t) + A_3(t)$$

$A_1(t) = 0.2$ [illegible] $(t) + I_2(t) + I_3(t) + I_4(t))$

$$A_2(t) = 0.021P(t) = 0.0021(P_{om} + p_{cs})(t)$$

$$A_3(t) = 0.001P(t)$$

where

N_{11} = number of NCS and LES
N_{12} = number of SES
N_{21} = number of LOS multichannel equipment
N_{22} = number of DTH SHF radio set
N_{23} = number of RAU radio set
N_{24} = number of MSRT radio terminal
N_u = number of NC

IV. EFFECTIVENESS CRITERIA

A. INTRODUCTION

The level of performance could be measured directly as a function of design parameters. However, this method involves a detailed engineering analysis and is beyond of scope of this thesis. Another, more aggregated approach is taken here. The TRI-TAC Figure of Merit (FOM) method is used as the model to evaluate levels of performance in this thesis. This method is a combination of additive weighting, utility theory, and effectiveness indexing and can be used to produce a single numerical level of performance. [Ref. 6: p.33].

The MOEs (Measure of Effectiveness) can be separated into the 16 elements referred to in chapter II. As mentioned above MOEs can be assessed quantitatively or qualitatively. Some MOEs must be quantitatively assessed after the test and evaluation of the new system in the future. Other relevant MOEs can be qualitatively assessed subjectively by using relative indices.

Among the 16 elements developed by TRI-TAC, only 4 relevant MOEs will be selected in this thesis. The method presented here can easily be expanded to include all 16 elements. In the Communication measures, Grade of service and Speed of service will be focused, and Jamming and Ease of reconfiguration will be selected as the Stability measures and Reorganization measures. However, Security parts will be ignored here.

Qualitative assessment will consist of taking each MOE and breaking it down into parameters that affect its performance. The assessment will be accomplished by comparing each alternative with a ranking of each alternative from best to worst in relation to the baseline standard [Ref. 6: p.19].

B. RELEVANT MOES

1. Grade of Service (GOS)

Grade of service is an estimate of the probability that a request for communication service will be blocked. For a network, it may be computed as a weighted average of blocking probability over all user pairs. The weights are computed based on selected characteristics of traffic needs for each user pair [Ref. 6: p. 39]. Grade of service estimations can be made separately for each type of service request, such as follows:

- Voice, data, TTY, or Facsimile

- Direct, indirect, broadcast, or conference
- Precedence level
- Secure, approved, or non-secure

Grade of service is often used as a circuit/network sizing parameter. It permits the evaluation of how much capacity is required to handle estimated traffic loads. Furthermore, Grade of service can be used as an indication of the effectiveness of a system network design which is constrained to a certain cost level.

Precedence of calls is a critical aspect in tactical communication system calculations. The higher precedence level such as Flash Override and Flash can preempt all other types of calls. These high priority service requests will rarely be blocked; therefore, their probability of blocking approaches zero.

As the general rule, multi-channel and pooled equipment significantly effect the GOS of a network. Switches such as the AN/TTC-39, which are normally described as non-blocking switches, also effect GOS in that inter-matrix blocking can result from various traffic conditions. An equipment such as a facsimile set can indirectly influence GOS in that one type of design can generate more traffic for a special picture transmission than an alternative design [Ref. 6 : p. 41-42].

The network design with the best GOS is the optimum for a fixed level of cost. GOS is defined as follows :

$$GOS = f\ (\ T,C,R,A,D\ )$$

where

T = Traffic volume by type of service

C = Channel of Capacity

R = Alternative Routing Capacity

A = Call or Message Arrival Probability Distribution

D = Call or Message Duration

2. Speed of Service (SOS)

Speed of Service is the expected time a message requires to move through the network from the last bit out of sending terminal to the last bit into the receiving terminal.

The speed of service is the time required to move a message through network. This implies that the message must pass through either a store and forward module (message switch) or through a torn tape relay.

The time for a message to pass through a network is a function of the following parameters :

- Switching Rate
- Routing Plan
- Human Message Handling
- Dialing Method
- Precedence Levels
- Processor Speed and Capacity
- Queueing

[Ref.6: p. 49-50].

3. Index of Survivability (SUB)

This is defined as the ratio of the average number of calls per unit time completed during a jamming stress to the average number of calls completed in an unjammed system, when the traffic demand is specified and held constant before and during attack. The index of survivability (jamming) assesses the ability of a communication system to continue to operate during a jamming attack.

This MOE treats two aspects of communication system. The first aspect is how well can the system continue to function when it is being electromagnetically jammed by an enemy. The second problem that is considered is that self-jamming where radiations from one part of the system interface with the operation of other components within the system.

In the qualitative analysis it must be assumed that all receivers can be jammed if their antennas are pointed in the direction of the FEBA (Forward Edge of Battle Area). The analysis of the receivers should take the form of how well they are designed to minimize the effect of a specific threat. Spread spectrum, frequency hopping and other anti-jam techniques should be considered.

The following subject areas should be considered in performing a qualitative analysis of this MOE.

- Signal-to-jammer power ratio
- Jamming signal type
- Transmission medium
- Channel capacity loss for given level of jamming attack
- Ease of control under jamming attack
- System sensitivity to jamming
- Ease of providing A/J capability

[Ref. 6: p. 65-66]

4. Ease of Reconfiguration (EOR)

Ease of Reconfiguration is the ability of the system to expand, contract, and reorganize to satisfy the range of subscribers demands.

The Ease of Reconfiguration measures the adaptability and flexibility of equipments that comprise the system. This measure was chosen to highlight the ability of a tactical communications system to operate under varying traffic demands and changing numbers of subscribers. This MOE can be measured either quantitatively or qualitatively.

In the qualitative method, the procedure is to take the qualitative aspects described below and make a subjective evaluation of how well the system, subsystem or equipment performs with respect to each aspect. A utility score can be assigned to each evaluation with respect to an accepted baseline and the scores may be combined to represent the assessment.

- Ability to add and subtract nodes without interfering with the communications capability of other connected nodes.
- Ability to add links.
- Ability to change connectivity (redundancy of connections) and capacity.
- Ability to change loop/trunk ratio.
- Ability to add service features.
- Variability of interfacing locations.
- Modularity of equipment.
- Ease of adding and removing subscribers.

Each of the aspects above contribute to the overall measure of Ease of Reconfiguration. By evaluating each aspect subjectively a qualitative assessment of this MOE can be obtained [Ref. 6: p. 78-79].

In many instances, entire systems or subsystems can not be evaluated as a whole and the anaysis must focus on a particular piece of equipment in the system. This instance calls for taking the basic system level MOE definition and customizing it to highlight the contribution of the equipment to the value of the MOE at the system level. The procedure is to isolate the contributing factors of a particular equipment to the MOE.

V. COST EFFECTIVENESS ANALYSIS

A. INTRODUCTION

To provide an optimal alternative for a new tactical communication system, the methodology of the concept of cost and effectiveness will be used in this chapter. This method will give the decision maker a better decision for selecting a tactical communication system in ROK Army.

Data dealing with the cost and the effectiveness of military communication system are very limited, if not classified. All data available to this analysis were collected through "The Korean Army military documents", "The U.S Military Equipment Cost Handbook", "The Parent Level Property Listing", "Unit Cost Analysis", among others. However, It is hard to adapt the available data directly to this analysis because of the rapid change of the economic and technological factors.

Furthermore, utility scores in each MOE are assigned subjectively by the author. Sensitivity analysis is included to assess the risk due to the data uncertainty.

B. ALTERNATIVES

Five alternatives are considered for selecting the best tactical communication system in the Korean Army. With respect to what kinds of methods for acquisition how many nodes or the access of switches to be fielded, five alternatives will present as follows :

1. Alternative 1 (Off-the-shelf)

Alternative one is to take the "off-the-shelf" acquisition method without having a phase of Research & Development. This alternative gives the best way of installing the new tactical communication system early in the near future, earlier than any other alternative. However, this may be an expensive acquisition method because this system must be purchased from a foreign nation. This way may be planned to procure for 5 years through the year 1991 to 1995.

2. Alternative 2 (NC: 3, Access:150)

Alternative two is to develop a new tactical communication system domestically. Within a division, three NCs can be fielded since the sector of every division is different in accordance with the terrain condition. Moreover, the capacity for access of switches can be limited to 150 subscribers at maximum, when considering the demand of access within one division. However, this self-developed system may take long time to be

fielded for the full operation. From the two limitation above, money can be saved at minimum, that is, the total cost in developing the NTCS can reduce largely, even though the capability of effectiveness may go down. The next four alternatives may be planned to be operated for 20 years through the year 1991 to 2010.

3. Alternative 3 (NC:3, Access: 200)

Alternative three is about same to the alternative two except that the capacity of access increases to 200 lines. This alternative can be more flexible for operation than that of alternative two in spite of the increase of cost.

4. Alternative 4 (NC: 4, Access: 150)

Alternative four is to field four NCs within one division. This can enhance the ability to insure the coverage of one division area. That is, this alternative can cover every division which has any different sector. This can respond rapidly in order to the needs of division under the changing operations.

5. Alternative 5 (NC: 4, Access: 200)

Alternative five is to choose four NCs and 200 access capacity. It may insure the complete communication service more than any other alternatives. Of course, the more cost should be considered due to the increase of accessibility.

C. EFFECTIVENESS EVALUATION

In this thesis, effectiveness measures will be assigned by the author using a subjectively evaluated index. Scaling for each index is from 1 to 10. The baseline measurement of 5 will be used as the baseline value for the current tactical communication system. Based on the baseline value, utility will be assigned by comparing the performance characteristics of each alternative to the capability of the current communications system.

1. Grade of Service (GOS)

Since the switches for all alternatives may use the similar digital switching systems, the channel capacity may be almost same. Only the parameter to represent the dominant difference between them can be the alternative routing capability. Comparing to the alternatives that three NCs will be field in one division, the other alternatives having four NCs can enhance the capability of alternative routing. Moreover, the switches of 200 access capacity can treat the messages more quickly than the switches with 150 access lines.

2. **Speed of Service (SOS)**

It is assumed that all alternatives will apply to the flood routing system, and Switing rate, Routing plan, Dialing method, and Processor speed and Capacity will be considered almost the same, since same NC digital switches will be fielded in this communications system configuration.

The measure of SOS may heavily depends on the parameter of Queueing. Alternatives to have more network lines and the capacity of accessibility will be assigned to the higher utility scores than others.

3. **Survivability (SUR)**

Conventional system has the vulnerability to be blocked almost, if there is a situation of enemy's jamming attack. NTCS, however, derives its survivability through a multi-channel grid network of mobile transmission paths. If one of the NC is destroyed by hostile action or is out of service for tachnical reasons, the switches will automatically route communications around the inactive NC. Survivability of the command posts is also enhanced by a reduction in electronic signiture. Electronically, all signal nodes and headquaters will look similar and the division headquaters will be extremely difficult to detect by electronic intercept.

Since the systems having more NCs can have the capability to move the NCs to the safer sites under no jamming, utility scores for alternative 1, 4, and 5 can be assigned higher than 2 and 3.

4. **Ease of Reconfiguration (EOR)**

The capability of the conventional VHF radio configuration is used as a baseline measurement. The NTCS system is interoperable with tactical and commercial communication systems. Furthermore, it provides connectivity with other military and host nation commercial systems amd a multitude tactical functional systems in the analog and digital modes. It employs a flood search routing algorithm that gives users the freedom to move within the network without changing telephone numbers. It also allows the network trunking to be reconfigured without the need to update routing tables in each switching element.

Since the alternatives 1, 4, and 5 have the four NCs, they have the flexibility to operate the NC according to any change of situation. That is, they can control and accommodate the demand to be requested by the new subscribers. Therefore, alternative 1,4, and 5 are assigned to the higher utility scores than others.

Based on the concepts of military operations, among 4 MOEs, survivability may be considered as the extremely critical factor for serving the satisfactory communications to win in the airland battle, so that it is weighted the most compared with other MOEs. Ease of reconfiguration may be more important element than GOS and SOS since the increasing accessibility may be required for the rapid mobile subscribers. On the other hand, GOS and SOS has little difference for assigning the weights, even though GOS may be weighted more than SOS. The weights of 4 MOEs as shown in Table 6 are assigned using the scale from 0 (the least important) to 100 (the most important) in this thesis.

Table 6 represents the utility assignments for the baseline evaluation.

Table 6. BASELINE UTILITY ASSIGNMENT

Alternative	GOS	SOS	SUB	EOR
A1	9	9	9	9
A2	6	6	6	5
A3	7	7	6	6
A4	8	8	8	7
A5	9	9	9	8
Weight	40	30	90	50

To get the FOMs, a linear additive function that is simple but useful is employed here. Using this linear function, any multi-attribute utility function can be locally approximated. This also fits the form used in many available decision aiding software tools ("Lightyear" is used in this thesis). First, the utility of the worst MOE evaluation is set at zero, the utility of best at 1. Second, all other utility values are obtained by linear interpolation between these extremes. Last, each individual MOE score is multiplied by its own weight and summed.

Therefore, the overall FOMs are calculated as follows :

$$FOM(A_1) = \frac{(9 \times 40 + 9 \times 30 + 9 \times 90 + 9 \times 50)}{210} = 9.00$$

$$FOM(A_2) = \frac{(6 \times 40 + 6 \times 30 + 6 \times 90 + 5 \times 50)}{210} = 5.76$$

$$FOM(A_3) = \frac{(7 \times 40 + 7 \times 30 + 6 \times 90 + 6 \times 50)}{210} = 6.33$$

$$FOM(A_4) = \frac{(8 \times 40 + 8 \times 30 + 8 \times 90 + 7 \times 50)}{210} = 7.76$$

$$FOM(A_5) = \frac{(9 \times 40 + 9 \times 30 + 9 \times 90 + 8 \times 50)}{210} = 8.76$$

D. COST EVALUATION

1. Alternative 1

The total system costs for the first alternative are shown in Table 7 in Appendix A. They consist of the investment costs which will be fielded each year in 5 years, and the operating & support costs in the proportion of the same amount.

The results of Table 7 is based on the following assumptions :

- All units are million dollars except where indicated.
- Investment costs for alternative one are calculated on the basis of the "FY 85 MSE procurement budget plan".
- The discount factors for 10 % which is used in DOD are used.
- Inflation and the learning curve factors are ignored here.
- Assignment of the O & S costs each year is based the deployment schedule and is similar to the cost profile in Figure 3.

The present total system costs will be $143. 52 million as shown in Table 7.

2. Alternative 2

The second alternative is to field 3 NCs with only 150 access lines for switches. The R & D costs, the investment costs, and the O & S costs are calculated using cost models in Table 5 based on the allocation of MSE system as followings :

- Three NCs and one LES are used in the system configuration of this alternative.
- A NCS or a LES is composed of 12 DTGs and 11 TEDs.
- Assume that estimated program size will be 250 Kbytes.

- 33 LOS multichannel radios and 36 SHF radios are needed for one standard division.
- 400 personnel are required to be assigned in order to operate a signal battalion within a division.
- The radio power for RAU or MSRT terminal is limited to 4 watts.
- 9 RAUs, 1080 DNVTs, and 685 MSRTs may be fielded within a division.
- It is assumed that this system is planned to operate for 20 years from the year 1991 to 2010.

The calculation for alternative two is like this : (SM)

$$I_1 = I_{11} + I_{12} = 4(0.585 + 0.109 \times 12 + 0.019 \times 11) + 0.01 \times 16 - 1.50 + 0.066 \times 250$$
$$= 8.40 + 0.16 + 15.00 = 23.56$$

$$I_2 = I_{21} + I_{22} + I_{23} + I_{24} = 0.057 \times 33 + 0.005 \times 36 + (0.0053 + 0.002 \times 4) \times 9$$
$$+ (0.0053 + 0.002 \times 4) \times 685 = 1.88 + 0.18 + 0.12 + 9.11 = 11.29$$

$$I_3 = I_{31} + I_{32} + I_{33} = 4.50$$

$$I_4 = I_{41} + I_{42} + I_{43} = 0.05 \times 33 + 0.05 \times 33 + 0.0001 \times 1080 = 3.3 + 0.108 = 3.41$$

$$I_5 = 0.15(I_1 + I_2 + I_3 + I_4) = 0.15(23.56 + 11.29 + 4.50 + 3.41) = 0.15 \times 42.76 = 6.41$$

$$I_6 = 0.023 \times 400 = 9.20$$

$$I_7 = 2.5 \times N_u = 2.5 \times 3 = 7.50$$

$$A_1 = 0.3(I_1 + I_2 + I_3 + I_4) = 0.3 \times 42.76 = 12.83$$

$$A_2 = 0.04 \times p = 0.04 \times 400 = 16.00$$

$$A_3 = 0.002 \times p = 0.002 \times 400 = 0.80$$

Therefore,

$R = 0.588 \times I = 0.588 \times 65.87 = 38.73$

$I = I_1 + ... + I_7 = 23.56 + 11.29 + 4.50 + 3.41 + 6.41 + 9.20 + 7.50 = 65.87$

$A = A_1 + A_2 + A_3 = 29.63$

As shown in Table 8 in Appendix A The present total system costs can reduce to $77.91 million after calcuation based on the cost profile as shown in Figure 3.

3. Alternative 3

The third alternative is to take 3 NCs and 200 access lines for a NCS. Total system costs are calculated using the cost models developed as shown in Table 5 of Appendix A and the results of calculations are in Table 9. Here there is no difference for calculation from alternative 2 except that 16 DTGs and 15 TEDs are used instead of 12 DTGs and 11 TEDs.

The present total system costs yield $80.57 million from the increase of accessibility for a NCS.

4. Alternative 4

The fourth alternative is to take 4 NCs and 150 access lines. Table 10 in Appendix A presents for the total system cost of this communications system configuration. The followings are the procedure of calculating costs using the cost models in Table 5.

$$I_1 = I_{11} + I_{12} = 5(0.585 + 0.109 \times 12 + 0.019 \times 11) + 0.01 \times 16 - 1.50 + 0.066 \times 250$$
$$= 10.05 + 0.16 + 15.00 = 25.66$$

$$I_2 = I_{21} + I_{22} + I_{23} + I_{24} = 0.057 \times 33 + 0.005 \times 36 + (0.0053 + 0.002 \times 4) \times 9$$
$$+ (0.0053 + 0.002 \times 4) \times 685 = 1.88 + 0.18 + 0.12 + 9.11 = 11.29$$

$$I_3 = I_{31} + I_{32} + I_{33} = 4.50$$

$$I_4 = I_{41} + I_{42} + I_{43} = 0.05 \times 33 + 0.05 \times 33 + 0.0001 \times 1080 = 3.3 + 0.108 = 3.41$$

$$I_5 = 0.15(I_1 + I_2 + I_3 + I_4) = = 6.73$$

$$I_6 = 0.023 \times 400 = 9.20$$

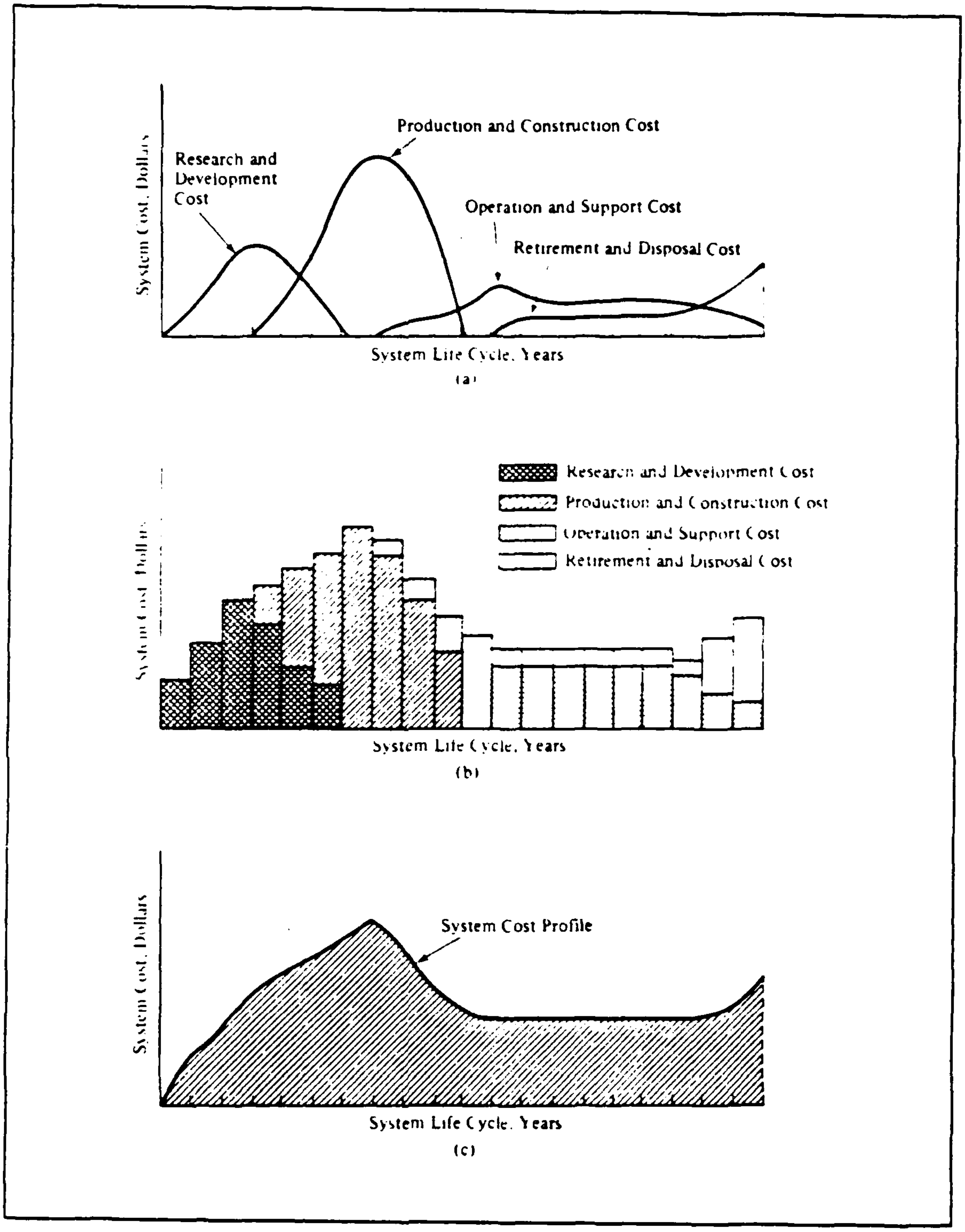

Figure 3. Development of Cost Profile

$I_5 = 2.5 \times N_u = 2.5 \times 4 = 10.00$

$A_1 = 0.3(I_1 + I_2 + I_3 + I_4) = 0.3 \times 44.86 = 13.45$

$A_2 = 0.04 \times p = 0.04 \times 400 = 16.00$

$A_3 = 0.002 \times p = 0.002 \times 400 = 0.80$

Therefore,

$$R = 0.588 \times I = 41.62$$
$$I = I_1 + \ldots\ldots + I_5 = 70.79$$
$$A = A_1 + A_2 + A_3 = 30.25$$

The present total system costs are $83.19 million as shown in Table 10 in Appendix A.

5. Alternative 5

The fifth alternative is to install 4 NCs and the 200 access lines for an NCS. Table 11 in Appendix A is shown for calculating the total system costs.

The present total system costs will rise to $90.79 million so that the performance levels may be enhanced.

E. THE BASELINE RESULTS

The cost and effectiveness level results are summarized in Table 7. Cost-effeciveness evaluation is calculated as the total system cost per a unit of effectiveness level for each alternative.

In the baseline cost-effectiveness evaluation, alternative 4 is the best one, followed by 5, 3, 2, and 1. The least preferred alternative is the "off-the-shelf" option.

Once the cost and effectiveness can be the main factors to be considered in selecting a good decision, the alternative five may be the best one among them. Here the C-E ratio of alternative one may be excluded as a possible choice due to the much dominent cost. Hence, alternative one may be excluded to make a good choice by a decision-maker based on the baseline of C-E.

Table 7. COST-EFFECTIVENESS BASELINE EVALUATION

Alternative	TSC($10M)	MOE	C-E RATIO
A_1	14.35	9.00	1.60
A_2	7.79	5.76	1.35
A_3	8.06	6.33	1.27
A_4	8.32	8.38	0.99
A_5	9.08	8.76	1.04

F. UNCERTAINTY

1. Introduction

When analying and comparing alternatives for the future communication systems, uncertainty may exist and reflect the great deal of risk for making a good decision. Three factors should be tested to see how sensitive the decision is with respect to the change of data. First, and most importantly, the subjective assessment of the effectiveness measures must be studied. Second, the effects of changing the weights in the overall FOM calculations must be investigated. Third, the impact of cost estimation errors must be investigated.

2. Range of MOEs, Costs, and Weights Change

Since MOEs are not known exactly, the possible range of likely change should be set. The MOEs for alternative one might rise or fall to five percent of the baseline values, however, other alternatives may be estimated to the change of 20 percent of the baseline values much more than the alternative one.

The TSC for alternative one may increase or decrease to five percent of the baseline cost evaluation because this will be the "off-the- shelf" way for acquisition which costs may be estimated more exactly from USA. On the other hand, the TSC for other alternatives may move up or down between the interval of 20 percent due to the high fluctuation of estimated costs about the "self-developed" system.

The weights of GOS and SOS may be altered to more 10 values or less 10 values because these two MOEs may not heavily affect the performance of the military communications systems. However, the weights of Jamming and EOR may be changed to more 10 values or less 20 values of the baseline evaluation since the weight of EOR for alternatives may not exceed that of Jamming in light of the military concept of operations.

3. Methodology

For the sensitivity analysis there needs a way of combining these three factors to see the effects of them simultaneously, and it is also needed that another way to work without requiring anymore information. Therefore, a "nested Monte Carlo" approach is employed.

First, "high", "low" and "medium" values for each range of variables (as shown in Table 15 - 20 in Appendix C) are assigned., Second, the sampling is nested, and all possible combinations are sampled. Last, the C-E ratio for each possible combination is calculated using ("APL" Program is used here.) :

$$\text{C-E Ratio} = \frac{Cost(A_i)}{\sum W_j MOE_j(A_i)}$$

4. Results of Sample Analysis

Figures 4, 5, and 6 show the results of sampling analysis through the methodology mentioned above using the " A Program Language " computer program and the " Minitab " statistics program.

From Figure 4 it is seen that both the distribution of alternative four that may be the best choice in the baseline and the one of alternative five may be similar. It means that one of two alternatives may be selected as a preferable choice by the dicision-makers, according to any other factors.

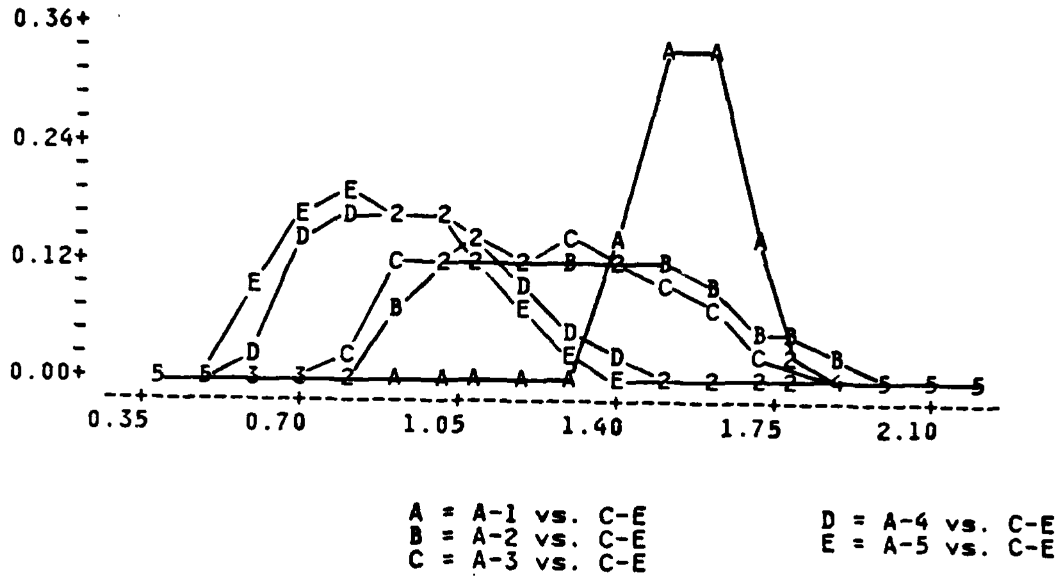

Figure 4. **Relative Distribution Graph**

C-E Ratio	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1
A-5	2	14	1662	3305	3606	3433	3421	2357	1321	470	78	4					
A-4		691	2856	3430	3227	3342	2893	1880	980	361	49	1					
A-3			4	536	2155	2523	2664	2482	2612	2428	1922	1241	677	279	79	9	
A-2				126	1264	2255	2460	2425	2322	2400	2250	1730	1138	714	298	94	17
A-1									140	2784	6813	6512	2861	400	7		

Figure 5. **Frequency Distribution Table**

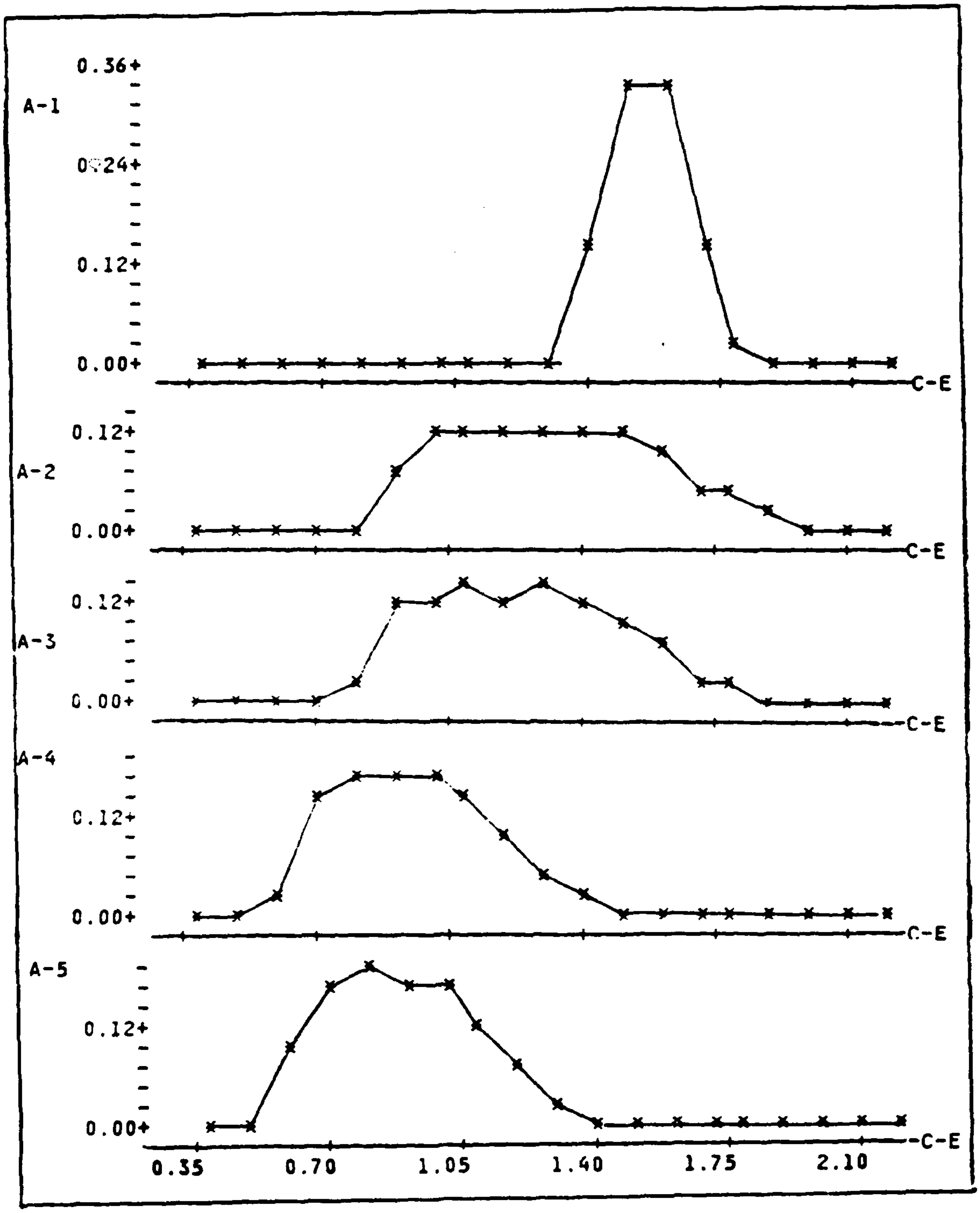

Figure 6. Relative Distribution Graphs for Five Alternatives

VI. CONCLUSION

A. FINDINGS

The findings of this thesis are as follows.

In the baseline evaluation alternative four is the best one to be taken as a tactical communications system in terms of the C-E ratio for the Korean Army. The preference order is:

$$A_4 \succ A_5 \succ A_3 \succ A_2 \succ A_1$$

In addition, alternative one, choosing the "off-the-shelf" method, may be excluded for comparison due the dominant C-E ratio.

On the other hand, in the sensitivity analysis it is seen that alternative four or alternative five may be the attractive one to be selected by the decision-maker. The effect of uncertainty captured in Figure 6 suggests a preferred ordering like:

$$A_4 \sim A_5 \succ A_3 \sim A_2 \succ A_1$$

There is little difference between the distribution of C-E values for A_4 and A_5, and little difference between the distribution of C-E values for A_2 and A_3 . However, there is a definite difference between A_1 and other alternatives.

Finally, it may be happen that alternative five may be preferred to alternative four on the reverse of the preference order of baseline evaluation. Therefore, more analysis should be required for which will be the better one to meet the needs of the tactical communications system in the Korean Army.

B. RECOMMENDATIONS

The author recommends that alternative four or alternative five be chosen for the tactical communications system of ROK Army. However, more information about other criteria is needed for selecting the alternative four or the alternative five alone in the near future.

APPENDIX A. TSC FOR ALTERNATIVES

Table 8. TSC FOR ALTERNATIVE 1 ($M)

YEAR	R & D	INVEST-MENT	O & S	DIS-COUNT FACTOR	DIS-COUNTED COST
1991		31.38	0.36	1	31.74
1992		31.38	0.72	0.9091	29.18
1993		31.38	0.96	0.8264	26.73
1994		31.38	1.32	0.7513	24.57
1995		31.38	1.68	0.6830	22.58
1996			1.68	0.6209	1.04
1997			1.68	0.5645	0.95
1998			1.68	0.5132	0.86
1999			1.68	0.4665	0.78
2000			1.68	0.4241	0.71
2001			1.68	0.3885	0.65
2002			1.68	0.3505	0.59
2003			1.68	0.3186	0.54
2004			1.68	0.2897	0.49
2005			1.68	0.2633	0.44
2006			1.68	0.2394	0.40
2007			1.68	0.2176	0.37
2008			1.68	0.1978	0.33
2009			1.68	0.1799	0.30
2010			1.68	0.1635	0.27
					143.52

Table 9. TSC FOR ALTERNATIVE 2 ($M)

YEAR	R & D	INVEST-MENT	O & S	DIS-COUNT FACTOR	DIS-COUNTED COST
1991	3.87			1	3.87
1992	7.75			0.9091	7.05
1993	9.68			0.8264	8.00
1994	7.75	4.61		0.7513	9.29
1995	6.58	8.56		0.6830	10.34
1996	3.10	11.20		0.6209	8.88
1997		13.17	1.48	0.5645	8.27
1998		11.86	1.48	0.5132	6.85
1999		9.88	1.48	0.4665	5.30
2000		6.59	2.07	0.4241	3.67
2001			2.67	0.3885	1.03
2002			2.67	0.3505	0.94
2003			2.96	0.3186	0.94
2004			2.96	0.2897	0.86
2005			2.67	0.2633	0.70
2006			2.67	0.2394	0.64
2007			2.07	0.2176	0.45
2008			2.07	0.1978	0.41
2009			1.48	0.1799	0.27
2010			0.89	0.1635	0.15
					77.91

Table 10. TSC FOR ALTERNATIVE 3 ($M)

YEAR	R & D	INVEST-MENT	O & S	DIS-COUNT FACTOR	DIS-COUNTED COST
1991	4.01			1	4.01
1992	8.02			0.9091	7.29
1993	10.04			0.8264	8.30
1994	8.02	4.78		0.7513	9.62
1995	6.82	8.88		0.6830	10.72
1996	3.21	11.61		0.6209	9.20
1997		13.65	1.51	0.5645	8.56
1998		12.29	1.51	0.5132	7.08
1999		10.24	1.51	0.4665	5.48
2000		6.83	2.12	0.4241	3.80
2001			2.72	0.3885	1.05
2002			2.72	0.3505	0.95
2003			3.03	0.3186	0.96
2004			3.03	0.2897	0.88
2005			2.72	0.2633	0.72
2006			2.72	0.2394	0.65
2007			2.12	0.2176	0.46
2008			2.17	0.1978	0.42
2009			1.51	0.1799	0.27
2010			0.91	0.1635	0.15
					80.57

Table 11. TSC FOR ALTERNATIVE 4 ($M)

YEAR	R & D	INVEST-MENT	O & S	DIS-COUNT FACTOR	DIS-COUNTED COST
1991	4.16			1	4.16
1992	8.32			0.9091	7.56
1993	10.40			0.8264	8.59
1994	8.32	4.96		0.7513	9.98
1995	7.08	9.20		0.6830	11.12
1996	3.33	12.03		0.6209	9.54
1997		14.16	1.51	0.5645	8.85
1998		12.74	1.51	0.5132	7.31
1999		10.62	1.51	0.4665	5.66
2000		7.08	2.12	0.4241	3.90
2001			2.72	0.3885	1.05
2002			2.72	0.3505	0.95
2003			3.03	0.3186	0.97
2004			3.03	0.2897	0.88
2005			2.72	0.2633	0.72
2006			2.72	0.2394	0.65
2007			2.12	0.2176	0.46
2008			2.17	0.1978	0.42
2009			1.51	0.1799	0.27
2010			0.91	0.1635	0.15
					83.19

Table 12. TSC FOR ALTERNATIVE 5 ($M)

YEAR	R & D	INVEST-MENT	O & S	DIS-COUNT FACTOR	DIS-COUNTED COST
1991	4.56			1	4.56
1992	9.12			0.9091	8.29
1993	11.40			0.8264	9.42
1994	9.12	5.43		0.7513	10.93
1995	7.75	10.08		0.6830	12.18
1996	3.65	13.18		0.6209	10.45
1997		15.51	1.60	0.5645	9.66
1998		13.96	1.60	0.5132	7.99
1999		11.63	1.60	0.4665	6.17
2000		7.76	2.24	0.4241	4.24
2001			2.88	0.3885	1.11
2002			2.88	0.3505	1.01
2003			3.20	0.3186	1.02
2004			3.20	0.2897	0.93
2005			2.88	0.2633	0.76
2006			2.88	0.2394	0.69
2007			2.24	0.2176	0.49
2008			2.24	0.1978	0.44
2009			1.60	0.1799	0.29
2010			0.96	0.1635	0.16
					90.79

APPENDIX B. DATA

A. REGRESSION ANALYSIS DATA

Table 13. COST IN ACCORDANCE WITH PROGRAM SIZE

Estimate Program Size (Kbytes)	Estimate Cost ($ M)
91	4.1
117	6.9
235	14.0

(Source : NAVELEX, 1977- 1982)

Table 14. RADIO COSTS

Equipment	Output (W)	Cost ($ M)
AN / PRC -77	1.3 - 2.0	0.002
AN / VRC -12	3.0 - 3.5	0.006
AN / GRC -160	1.5 - 2.0	0.002
AN / GRC -103	15.0 - 30.0	0.057
AN / VRC - 47	12.0	0.059

(Source : Military Cost Handbook, 1982)

B. COST, MOE, WEIGHT CHANGE FOR ALTERNATIVES

Table 15. WEIGHT RANGE OF CHANGE

Weight	Minimum	Medium	Maximum
W 1	30	40	50
W 2	20	30	40
W 3	70	90	100
W 4	30	50	60

Table 16. COST RANGE OF CHANGE ($M)

Cost	Minimum	Medium	Maximum
C 1	136.8	144.0	151.2
C 2	62.4	78.0	93.6
C 3	64.8	81.0	97.2
C 4	66.4	83.0	99.6
C 5	72.8	91.0	109.2

Table 17. MOE-1 CHANGE FOR ALTERNATIVES

Cost	Minimum	Medium	Maximum
A 1	8.55	9.00	9.45
A 2	4.80	6.00	7.20
A 3	5.60	7.00	8.40
A 4	7.20	9.00	10.80
A 5	7.20	9.00	10.80

Table 18. MOE-2 CHANGE FOR ALTERNATIVES

Cost	Minimum	Medium	Maximum
A 1	8.55	9.00	9.45
A 2	4.80	6.00	7.20
A 3	5.60	7.00	8.40
A 4	6.40	8.00	9.60
A 5	7.20	9.00	10.80

Table 19. MOE-3 CHANGE FOR ALTERNATIVES

Cost	Minimum	Medium	Maximum
A 1	8.55	9.00	9.45
A 2	4.80	6.00	7.20
A 3	4.80	6.00	7.20
A 4	7.20	9.00	10.80
A 5	7.20	9.00	10.80

Table 20. MOE-4 CHANGE FOR ALTERNATIVES

Cost	Minimum	Medium	Maximum
A 1	8.55	9.00	9.45
A 2	6.00	5.00	4.00
A 3	4.80	6.00	7.20
A 4	5.60	7.00	8.40
A 5	6.40	8.00	9.60

APPENDIX C. MOBILE SUBSCRIBER EQUIPMENT (MSE)

This appendix presents the portions of the operational concepts for the MSE system as developed by the US Army Signal Center, Fort Gordon, Georgia.

A. MSE SYSTEM CONCEPT

The MSE system is a multichannel communication network for use at the division and corps level. The network is composed of primary nodes that form a backbone system and extention nodes and Radio Access Units (RAU) that provide users access to the system. The primary nodes are interconnected by multichannel radio links to form a grid system. Extention nodes and RAUs access the communication network by means of multichannel radio links connecting them to primary nodes.

The MSE system is designed to provide communication support as an integrated network at the corps and division level. For a corps force composed of 5 divisions, a total of 56 primary nodes will be available in the organic corps and division signal units to form the backbone system. Each of the primary nodes in the backbone is generally connected to four other primary nodes to form the backbone grid. Extention nodes and RAUs are usually provided multichannel radio links to two of the primary nodes in the backbone system, with one link active while the other is in a standby condition to provide backup as needed.

Extention nodes provide access to the backbone network for static subscribers. Mobile subscribers are provided access to the network by means of the Radio Access Units. Each of the individual pieces of terminal equipment used by subscribers are assigned a directory number that remains constant regardless of where the subscriber may move within the system. This feature allows subscribers to be accessed regardless of their location within the service area of the system.

All terminal equipment is owned and operated by the using unit. The elements of the long haul communications network are owned and operated by signal units at the respective levels of command.

B. MSE FUNCTIONAL ELEMENTS

The functional elements of the MSE system are :

1. Node Centers
2. Large Extention Switch

3. Small Extention Switch
4. Radio Access Units
5. Line of Sight (LOS) multichannel radio assemblages
6. Super High Frequency (SHF) radio
7. System Control Center (SCC)

1. Node Center Switch

One node center is located at each primary node. Each NC performs tandom functions or 12 trunk groups. The NCS is an all digital switch that performs flood search routing for locating subscribers of the network. The switch will be used for tandom switching only, and typically will not provide loop service for subscribers. The NCS will accommodate 16 digital transmission groups (DTG), 15 of which will be encrypted by KG-94 trunk encrypton devices (TEDs).

The NCS will provide switching for 25 local loops for node management and control purpose only. The NSC will also be equipped with a secure engineering orderwire control unit.

2. Extention Switches

Large and small extention switches provide primary user access to the communications network and are the main components large and small extention nodes respectively. Small extention switches provide access for 30 users, while large extention switches will handle up to 150 users. Users provide their own terminal equipment and connection to the switch is by means of wire and cabie. The primary wire line terminal device is the telephone. Facsimile (FAX) and microprocessor terminals may also be supported through the extention switches.

3. Radio Access Units (RAU)

RAU provides access to high priority mobile subscribers throughout the battlefield and each RAU can handle up to 25 mobile subscribers. The RAUs will generally be assigned to each primary node , of which one will be collected with the elements of the primary node while the other is located at some other location and connected to the primary node by LOS dadio. The locations of the second RAUs assigned to a primary node are chosen to provide maximum accessibility to users throughout the area covered by the MSE system.

As with wire terminals, users own and operate their own equipment to gain access to the communications net through the RAUs. Ths user terminal is known as a

Mobile Subscriber Radiotelephone Access Terminal (MSRT), and provides a user discrete addressability within the MSE system.

4. **LOS Multichannel Radio**

LOS multichannel radio assemblage provide connectivity between the elements of the MSE system. Four assemblages will be deployed at each node. This radio will operate in the frequency ranges of 220-405 MHz and 1350-1850 MHz.

5. **SHF radio set**

These radio sets provide extention nodes the ability to seperate the extention switch from the LOS radio assemblage. One SHF radio set is carried by each extention switch and the other by the small LOS radio assemblage that connects the extention switch to the primary node. These low powered radio sets have a range of 5 Km.

6. **System Control Center (SCC)**

The SCC provides technical control for the MSE system. The SCC controls activations of links and node centers, performs frequency management tasks, and provides systems analysis and displays for use by the various C-EMS elements. The SCC maintains a system database that is updated and distributed by means of continuous exchanges of data between the SCC and the node centers that make up the system.

Each SCC will be collocated with a primary node, and will generally be more than one SCC in a system. One of the SCCs will be designed the master SCC, while any others will function as backup, or slave SCCs. Database exchanges will also be conducted on a continuous basis between the master and slave SCCs.

C. SYSTEM CHARACTERISTICS

There are a number of significant advantages which MSE will provide over current division signal battalion capabilities. These advantages accrue in both personnel savings and operational enhancements.

The followings show the characteristics of the MSE system:

- MSE will provide division and brigade commanders an upprecedented degree of mobility on the battlefield. MSE will, to a great degree, eliminate terrain dependence for the division's combat commanders. Current plans call for the division to be equipped with four MSE switching nodes and approximately 200 MSRT units. The capability for this type of fredom of action and mobility on the battlefield will be a tremendous combat multiplier.
- MSE will provide the division commander with an unprecedented degree of stability in his command and control system.
- MSE will eliminate the current interface problem between the corps signal brigade and the division signal battalion.

- MSE will provide the signal officer with a greater capability to reduce battlefield electronic signatures.

LIST OF REFERENCES

1. Signal Corps, *Army Communicator*, Summer 1986.

2. Quade, E. S., Washington Operations Research Council, *Cost Effectiveness Analysis*, Praeger Publications, New York, 1967.

3. Benjamin S. Blanchard, *Logistics Engineering and Management*, Prentice Hall Inc., Third edition, 1986.

4. Fort Monmouth, N.J. Joint Tactical Communications Office, *Life Cycle Costing, Volume 3*, April 1978.

5. Gene H. Fisher, *Cost Considerations in Systems Analysis*, Office of the Assistant Secretary of Defense, December 1970.

6. Fort Monmouth, N.J. Joint Tactical Communications Office, *System Effectiveness Volume 2*, November 1974.

7. Department of Defense, *Life Cycle Costing Procurement Guide (interim)*, July 1970.

8. J. Morley English, *Cost-Effectiveness*, John Wiley Sons, Inc., 1968.

9. Joint Tactical Communications, Cost-Effectiveness Program Plan, *Military Personnel and Training Costs, Appendix D*, October 1976.

10. John F. Schank, Susan J. Bodilly, Richard Y. Pel, Unit Cost Analysis, *US Annual Recurring Operating & Support Cost Methodology*, Rand, 29 April 1986.

BIBLIOGRAPHY

1. Hitch Charles J. and Roland McKean, *The Economics of Defense in the Nuclear Age*, Harvard University Press, Cambridge, Massachusetts, 1960.

2. LTC. Gerard P. Brohm, *Transitioning to MSE in the Division*, US Army War College, 16 April 1985.

3. US General Accounting Office, *Evaluation of Army's MSE Program*, 16 July 1985.

4. Defense Communications Agency, *Analysis of Planned Army Ground Mobile Forces Satellite Use in support of MSE*, 16 June 1986.

5. US Army War College, *Maintenance Concept for MSE*, 23 March 1987.

6. US Army War College, *Corps Communications for the Airland Battle*, 16 July 1985.

7. Fort Monmouth, N.J, *An Analysis of the JTIDS as a MSE Alternative*, 21 September 1979.

8. Fort Monmouth, N.J, *Cost Uncertainty Analysis Model*, Life Cycle Costing Volume III, Appendix G, May 1976.

9. William F. de Dufour, *Description of TRI-TAC Equipment Acquisition Program*, 11 November 1977.

10. Bradford J. Bryant, *A Model to Forecast Performance of US Army Tactical VHF-FM Communications*, Master's Thesis, March 1986.

11. William B. Collins, *Application of Selected Software Cost Estimating Models to a Tactical Communications Switching System*, Master's Thesis, March 1982.

12. Joint Tactical Communications Office, *TRI-TAC Technology Forecast*, October 1974.

13. Brin A. Tolliffe, *A Knowledge based System for the Design of MSE Communications Network*, Master's Thesis, 13 Feburary 1986.

14. Hwang, Tae Kyun. *Cost-Effectiveness Methodology for Evaluating Korean International Communication System Alternatives*, Master's Thesis, March 1987.

15. TM 11-5805-681-12-1, *AN/TTC -39(V) Operator's & Organizational Maintenance Manual*, 16 July 1984.

16. Division Property Book Office, *Parent Level Property Listing*, 3 November 1987.

17. GTE, *The US Army's Choice*, Pamphlet, 1987.

18. Jane's Company, *Jane's Military Communications*, 1987.

19. Information Clearing House Inc., *The Directory of Defense Electronic and Service*, 1982.

20. William D. Stanley, *Electronic Communications Systems*, Prentice Hall Inc., 1982.

21. Barbara F. Ryan, *Minitab*, Second Edition, Duxbury Press, 1985.

22. Lightyear Inc., *Lightyear (The Dicision Modeling Software)*, 1984.

23. US Department of the Army Field Manual, FM 24-1, *Combat Communications*, September 1976.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3.	Department Chairman, Code 54 Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943	1
4.	Professor Kent D. Wall, Code 6419 Defence Resources Management Eduation Center Naval Postgraduate School Monterey, CA 93943	1
5.	Professor Dan C. Boger, Code 54BO Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943	1
6.	Library, P.O.Box 77 Gong Neung Dong, Dobong Ku Seoul 130-09 Republic of Korea	1
7.	Yim, Jae Yong SMC 1216 Naval Postgraduate School Monterey, CA 93943	1
8.	Park, Nai Soo SMC 1831 Naval Postgraduate School Monterey, CA 93943	2
9.	Seo, Young Uk (150-02) 1130-27 Wha Gok Dong Kang Su Ku Seoul, Korea	5